A Plausible Explanation for Ultra-High-Energy Cosmic Rays:

Speculating About the Driver of the Mysterious Ultra-High-Energy Cosmic Ray (UHECR) Phenomenon, in the Context of Extra-Terrestrial Intelligence

Ken Zahler zahler_philosopher@nym.hush.com
First Edition: July 1, 2018
This Edition: June 24 , 2025

Introduction

Popular YouTube science communicator Dianna Cowern, also known as Physics Girl, is a graduate of MIT with a bachelor's degree in physics. Among her sizable catalog of videos is Strange Unexplained Cosmic Rays, discussing the mysterious and rare Ultra-High-Energy Cosmic Rays (UHECRs) which have been detected at cosmic ray observatories. The video was inspired by a chapter in a book from Jorge Cham and Daniel Whiteson called We Have No Idea: A Guide to the Unknown Universe. The book encourages us to get excited about the "uncharted territory" of human knowledge with a laugh-out-loud nerd funny, yet thoroughly physics-based look into some of the "big questions" for which there are no clear, agreed-upon answers.

In Chapter 11, Dr. Cham (Ph.D. engineering) and Dr. Whiteson (Ph.D. physics) note that astrophysicists have considered every scenario they could think of in which a cosmic ray *particle* might acquire the energies calculated for UHECRs, and still fall short on the order of thousands of times too low. In cases like this when there is no clear, agreed-upon explanation for a phenomenon, it is standard practice in science to maintain a list of all of the even marginally reasonable explanations that can be thought of by everybody; while also maintaining the possibility that all of *those* may still be wrong, and the truth a true unknown. This is the territory explored by the book.

Since prosaic sources such as supernovae and black holes had already been considered by the astrophysicists, Cham and Whiteson's list includes highly speculative and largely philosophical explanations. One of these is an item which is extraordinarily rare among legitimate academics (such as Cham and Whiteson), in that it is based on the activity of an extra-terrestrial intelligence. This is that UHECRs may be the "left-overs," or "pollution from," "particle accelerator" experiments made by "alien scientists ... intelligent extraterrestrial beings."

The Physics Girl video provides an excellent overview of the basics of UHECRs in a format which is simultaneously vigorous and rigorous, and also includes both illustrations and voice-over from Cham and Whiteson themselves. This paper will continue onward from the video and introduce it's own possible explanation for UHECRs involving aliens. There are some basic physics concepts which are needed to make this case, so they will be reviewed first.

Reaction Engines

Jet and rocket engines both fall into the broader category of reaction engines, which are so named because they work in accordance with Newton's Third Law of Motion, that every action has an equal and

opposite reaction. Reaction engines require reaction mass, which is material intended to be shot out the back of the engine. In terms of Newton's law, the acceleration of reaction mass backwards is the action, and the equal and opposite reaction is thrust. Action and reaction are changes in momentum, which, importantly, is mass times velocity. A change in momentum is an impulse.

The reaction mass used by jet engines is mostly air drawn in from the atmosphere, along with the comparatively small amount of fuel which is burned and leaves the engine as exhaust. With no atmosphere available, though, a rocket must carry all of its reaction mass with it from the beginning of flight, a significant penalty. There are very many possible configurations of reaction mass for a rocket system; but in all cases it is referred to as propellant. When the propellant is ejected from the rocket engine, it is referred to as exhaust. A common example would be kerosene and liquid oxygen *propellants*, burned to release energy, with the *exhaust* gasses jetted through a nozzle, straight out the back of the engine. The velocity with which the exhaust exits an engine is the exhaust velocity.

There is a very close analogy between the thrust of a rocket and the recoil of a gun, since they both result from Newton's Third Law. In a gun, the action is the acceleration of a bullet outward, and the reaction is the gun's recoil. Note that the lighter bullet is accelerated much more than the heavier gun. It is the change in momentum, mass times velocity, which is equal and opposite for the bullet and the gun. Muzzle velocity is analogous to exhaust velocity here; the higher the muzzle velocity, the greater the recoil for a given mass of bullet.

Specific Impulse

There are actually *two* key measures of rocket engine performance: thrust and specific impulse. Conceptually, specific impulse (I_{sp} or I_s) is a measure of how efficiently a rocket system uses its limited, carried-on-board reaction mass to generate acceleration. Mathematically, though, specific impulse is nothing more than the exhaust velocity of the reaction mass ejected from the engine... divided by the standard acceleration of gravity, which is a constant (g_0). This division is why it is called "specific" impulse, and results in units of seconds, units which are not at all useful for understanding it.

It appears that this specification is done so that the numerical value of specific impulse will be the same whether using the Système International (basically metric units) or the English Engineering System (basically imperial units), since both systems include seconds as a unit. This can mitigate engineering errors in translation between languages, and is generally a good idea.

Still, just where do these rocket scientists get off calling a velocity an impulse, which is a change in momentum? Well, the mass of the propellant is the same when it is sitting in a tank on board the rocket as it is when it is shooting out the back of the engine. As such, the change in momentum of the propellant is fully driven by the change in its velocity alone.

Tsiolkovsky Equation

Before a rocket fires, it starts off with some initial mass. When the rocket stops firing, in ends up with some final mass. In the simple case of a single rocket stage, the decrease in mass is entirely the result of propellant being consumed and ejected from the engine while firing. The percentage of a rocket's

initial mass which is comprised specifically of propellant mass is referred to as the propellant mass fraction. The term mass fraction can be generalized to refer to a percentage of a rocket's initial mass devoted to any particular type of thing, such as: tankage and plumbing, engines, fairings, control hardware, habitation, payload, astronauts, Tang, etc. Also note that the reason a rocket stage fires is to achieve an acceleration, that is, a change in velocity or delta-v.

The Tsiolkovsky Equation relates delta-*v*, exhaust velocity, and the rocket's initial and final masses (from which propellant mass fraction can be determined). It is the equation where specific impulse is at its most relevant, but it doesn't have I_{sp} as an input; specific impulse must first be converted back into exhaust velocity, which is what it really is. Note that because of cold-war tensions, this equation is known by some people simply as “The Rocket Equation,” as well as by other names. It is a fair candidate for the title of *equation number one* in rocket science.

To get a feel for the significance of specific impulse, consider the Saturn V rocket used in the Apollo moon landing program. About eighty-five percent (!) of its gross lift-off weight was accounted for by the weight of fuel and oxidizer. That is, the Saturn V had an overall propellant mass fraction of 85%. Meanwhile, the overall dry mass fraction – the mass fractions of everything else *combined* (including engines *and* Tang) – was only 15% of the total mass of the gigantic rocket on the launch pad. This is a typical number.

Electric Propulsion

The oppression of propellant mass fraction is a result of the comparatively low specific impulse of these rocket systems, relative to the amount of delta-*v* required to achieve or escape Earth's orbit. Once in orbit, though, much lower thrust requirements allow electric propulsion systems to have an order of magnitude higher specific impulse. These are currently operational in satellites, and include: ion thrusters, pulsed plasma thrusters, and Hall-effect thrusters. While these electric thrusters use electricity (generally from solar panels) for energy, they are still reaction engines and so still require that propellant (xenon, hydrogen, Teflon, etc.) be carried on board and ejected from the thruster. As far as we know, this is the only way to generate translational motion – point to point motion, as opposed to rotation – in space, in accordance with Newton’s Third Law. The term “exhaust” still applies to any propellant exiting a reaction engine (or motor, or thruster, la da dee), whether accelerated thermodynamically or electrically.

Consider the following: a variation of the Tsiolkovsky Equation can be graphed (for a single rocket stage), with delta-*v* along the horizontal axis and dry mass fraction (a percentage between zero and one hundred percent) along the vertical. This will graph as an exponential decay curve, showing that as the required delta-*v* for a mission increases, the dry mass of the rocket (that which remains after all the propellant has been consumed) decreases rapidly. Specific impulse determines the curvature of the graph, and in the mission design phase the curve defines a trade-off between the cumulative delta-*v* available and the dry mass fraction. Basically, higher delta-*v* requires higher propellant mass fraction, at the expense of spacecraft dry mass (which includes all vehicle components, accommodations, and payload).

A higher specific impulse results in a flatter and overall higher curve, representing a more favorable trade-off environment. A consequence of this is that if specific impulse could be increased many

orders of magnitude beyond today's electric thrusters, it would allow the dry mass fraction of a spacecraft to be much higher for any given delta-*v* requirement. This would allow rockets that are more like those in science fiction: *not* mostly propellant tank. An engine with *ultra-high* specific impulse may also allow significantly higher delta-*v* and therefore faster transits and longer ranges. Of course, higher delta-*v* with heavier ships will also require higher thrust... meanwhile today's electric thrusters present comically low thrust. They make up for it just enough by being able to run continuously for up to months, though. A spaceship which brings together all of these factors might comfortably (sort of) putter around a solar system.

Keep in mind that specific impulse is nothing more than an indirect representation of exhaust velocity (suggested reading: Rocket Propulsion Elements, George P. Sutton and Oscar Biblarz, Wiley).

Linear Particle Accelerators

Interestingly, in one of the passages from Cham and Whiteson in the Physics Girl video, they mention the Large Hadron Collider at CERN, which is basically a modern atom smasher experiment. It makes use of linear particle accelerators, also called linacs – machines which use dynamic electric fields to accelerate charged subatomic particles to speeds approaching the speed of light. The linacs at CERN are an example of a known, proven, human technology capable of accelerating tiny masses to velocities many, many orders of magnitude higher than the exhaust velocities of the best electric thrusters. In fact, if we were to think about how to design an ultra-high specific impulse rocket motor, and we asked ourselves what known, proven technology results in the highest final velocity of anything ever, the answer would be the linac.

Obviously, the Large Hadron Collider would make for a crappy rocket engine. The point is that, in principle, it should be possible to engineer an electric thruster with an astronomically high specific impulse (ha ha very punny), and that such a thruster could plausibly be based on the principles used in linear particle accelerators. Note, however, that to serve as a spacecraft's main propulsion (in vacuum), such a thruster would also need a very-many-orders-of-magnitude (Avogadro-style) increase in thrust compared to today's electric thrusters. This is an engineering problem, solvable if the accelerator is designed from the beginning to be a motor. Thrust is proportional to the flow of reaction mass, which for electric thrusters is microscopically low, and for the particle beams within CERN as an engine, effectively zero.

Synthesis

So here it is: an alternate take on the alien explanation for these UHECRs is that, instead of being "the result of alien experiments," as paraphrased by Cowern, these energetic particles may be individual (or tightly grouped) propellant particles, randomly diverging from the exhaust plumes of alien, linac-based reaction engines.

If humans were to design a linac-based reaction engine as a natural progression from our current technology, it would probably: be constructed more like a Dielectric Wall Accelerator (DWA) than CERN's radio frequency (RF) accelerators, use charged microscopic water ice crystals as propellant (ice, ice, baby!), and be powered by a full Rankin cycle nuclear reactor. An extraterrestrial

technology thousands of years ahead of us would probably use: nanomachinery accelerator *arrays*, large flows of monoatomic ion propellant, and some power source capable of easy mass-to-energy conversion (editorial: anti-matter ain'ti it). In either case, the exhaust plume of such a rocket motor would transform any matter in its direct path into a molecular mist. Any ethical species would be careful to aim it away from life or any other valuables – thus the “randomly diverging" particles above. (Any species using it as a weapon, sooner or later, will probably secure for themselves the Darwin Great Filter Award.)

Speck-ulation here about specific conceivable technologies is fun but secondary. The key points of this discussion follow:

1) At a quantum/ Newtonian level of understanding, reaction engines are the only way to generate translational acceleration in space, regardless of biological species.

2) The maximum *economic* specific impulse (exhaust velocity) is always desirable for a reaction engine, since this maximizes the quantity which can be traded off between spacecraft accommodations and speed, in accordance with the Tsiolkovsky Equation. (An exhaust velocity of “99.9999[…] % of *c*,” the calculated velocity of the "OMG particle," would be really really great actually).

3) A sufficiently advanced, linac-based reaction engine, produced by an extra-terrestrial intelligence for transportation, might generate an exhaust plume of particles with the characteristics of Ultra-High-Energy Cosmic Rays. The alien engineers would be motivated to use an ultra-high specific impulse engine because of point 2 above.

Note that deliberate, technology-based systems generally exhibit much higher performance than their naturally occurring counterparts: cars go faster than horses, air conditioners cool better than breezes, oxyacetylene torches burn hotter than forest fires, the Haber process fixes more nitrogen than lightning, etc., etc. It is reasonable to expect that cosmic rays coming from a machine could be much more energetic than those coming from a supernova. Also note that even though it is intended to accelerate the propellant to speeds close to the speed of light, an actual *ship* using the engine would only ever accelerate to a very low percentage of light speed, because the ship is much, much, heavier.

Conclusion

It is probably safe to say that most physicists believe in evolution and abiogenesis. As such, the possibility that there are linacs out there being used by aliens is defensibly non-zero. On any scientific list of candidate models to explain an unexplained phenomena, statistically speaking *each one of them* is likely not to be true! In this context, to exclude a plausible explanation with prejudice, simply because it involves extra-terrestrial intelligence, would be intellectually dishonest. So hats off to Cham, Whiteson, and Cowern for at least putting it on the list, despite any peril of unwarranted ridicule from peers.

There is one final interesting point to make about this linac-based thruster concept. When the propellant exhaust velocity is high enough that relativistic effects are significant, the whole concept of using specific impulse to represent exhaust velocity breaks down. Assuming an awesomely prolific energy source, the propellant could actually weigh much more as it leaves the thruster (a bonus) than it did while sitting in its tank… relatively speaking.